APPENDIX G

AD VANCE

Advanced Driver and Vehicle Advisory Navigation Concept

Traffic Related Functions
Evaluation Report (7 of 7)
Documents # 8460.00

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ADVANCE Evaluation

Relationships among Travel Times

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Executive Summary

In a dynamic route-guidance system, through movements will likely be by far the most prevalent movements at intersections. Therefore it will be useful to predict left and right-turning travel times from known through-movement travel times on a segment of road. The purpose of the *Relationships among Travel Times* task is to determine a method for predicting turning-movement travel times from through-movement travel times.

Data were collected over a three-week period in the summer of 1995 on a series of specially-designed study routes, focusing on one target link on the section of Dundee Road between Elmhurst Road and Wheeling Road in Wheeling, Illinois. Two types of comparison between turning-movement and through-movement travel times were made. First we evaluated the existing ADVANCE procedure of adding empirically-derived constants to through-movement travel times to predict turning-movement travel times. Then we built a series of regression models to determine if a more complex relationship between left-turn and through-movement travel times exists.

Without additional information on signal timings, adding a constant to through-movement travel times is generally a fairly accurate method of predicting turning-movement travel times. However the accuracy of this model varies over the links and turning movements that were analyzed. The regression models using through-movement travel times and intersection-approach traffic volumes did not produce forecasts of left-turn travel times that were much better than those obtained using the method of adding a constant to the through-movement travel times.

However when signal timing information was input to the regression model a better prediction of left-turn travel time could be made. This indicates that signal timing is the most effective predictor of turning-movement travel times. Without prior knowledge of signal timings it is extremely difficult to accurately predict turning-movement travel times from known through-movement travel times and detector traffic volumes on intersection approaches.

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1 Introduction

Travel-time data for through movement links will most likely be the most prevalent of all types of travel-time data because through movements are generally executed more frequently than turns. Hence, deriving travel times for turning-movement links from links with the same base segment with a through movement is desirable for dynamic travel-time prediction. For example, if a through-movement link experiences heavy congestion as determined from corresponding probe reports, then the adjacent left-turning movement, in all likelihood, is also experiencing heavy congestion. However, without a left-turn probe report, TTP (Travel-Time Prediction) will predict the time as being equivalent to the SP (Static Profile estimate. If the relationship between through and left-turn travel times can be determined a more accurate prediction, based on the left-turn travel time, can be made.

The ADVANCE design included a provision for estimating travel times for turning movements based on probe reports for through movements. This task requires travel-time data from relevant combinations of links (e.g., through and left-turn travel times from the same segments at the same times). The procedure, described in detail in Section 2, consists of adding a constant to the link travel-time estimate for the through movement to obtain a corresponding travel time for the left or right turn. This report presents the results of the evaluation of this procedure. The evaluation actually consists of two parts. In the first part we assess if the constants added to through-movement travel times are of an appropriate magnitude. The second part of our evaluation attempts to answer the question of whether non-constant quantities would have provided more accurate predictions of turning-movement travel times.

The results from the evaluation may be summarized as follows: there does not seem to be a simple formula which would be much of an improvement over a constant. Promising results were obtained only when we input signal-timing data to a regression model. The constants used by ADVANCE are reasonably accurate but could perhaps be slightly improved in a straightforward manner.

2 Turning-Relationships Procedure

Before probe observations were available for static-profile updating, travel-time estimates were obtained using the Network Flow Model (NFM) described in detail in Sen et al. (1996). For a given link l and time interval i the travel time for a through movement given by this model is $t_{l,i}$ and the corresponding time for a left turn is $l_{l,i}$

Suppose for any time interval i and day d, the through-movement link travel time is $T_{l,i,d}$ and the corresponding link travel time for a left turn is $L_{l,i,d}$. The time intervals for dynamic forecasts are five minutes long, while the NFM estimates are for much longer intervals (the off-peak interval covers the period from 1:00 pm to 4:00 pm and the peak period lasts from 4:00 pm to 6:00 pm). However, each dynamic-estimate interval is contained within an NFM interval. Therefore, corresponding to a dynamic-estimate interval is an NFM interval and a corresponding NFM estimate (the Base Data, or BD estimate) for each link and movement. The intervals i referred to above are the five-minute dynamic-estimate intervals.

The ADVANCE procedure estimates left-turn travel times when no probe reports for left turns are available as follows:

$$L_{l,i,d} = T_{l,i,d} \cdot {}_k\, l_{l,i} - t_{l,i} \qquad (1)$$

In this way ADVANCE uses historic data on the difference between the left-turn and through-movement travel times on a pair of links sharing the same base segment to predict a left-turn travel time from a through-movement travel time within the same five-minute interval. The formula for right turns is similar. We evaluate the appropriateness of this method in Section 4, where the actual differences between turning and through-movement travel times are presented and compared to the NFM Base Data (BD) estimates.

3 Study Area and Data Collection

During the summer of 1995 an average of twelve vehicles per day were driven four days a week over an eleven-week period. During this time almost 60,000 miles were driven to produce over 50,000 link reports within a confined study area. The ADVANCE evaluation project comprises a number of tasks. The 11-week data-collection period yielded probe data for the analysis of several subtasks. Data for the turning-relationships task was gathered at the end of the data-collection period.

3.1 Study Links

During the last three weeks of data collection in the Dundee Road study area the vehicles were used to evaluate turning-movement travel-time predictions. In this case each driver was given a set of randomly-drawn routes, to be driven in sequence, which covered the links shown on Figure 1. The target section of Dundee Road identified in the Evaluation Test Plan (Links A and a) is clearly shown. On Link H/h the drivers were permitted to stop and study the rest of the routes they had been assigned to drive. Data collection on the turning-relationships routes generally yielded more than 1500 usable MNA reports per day. Over half of these reports are on Dundee Road (the links labelled A, a, B, b, E and e) and are also used in deriving static profiles.

3.2 Data-Collection Design

The data-collection effort for this evaluation task had to be carefully designed for several reasons:

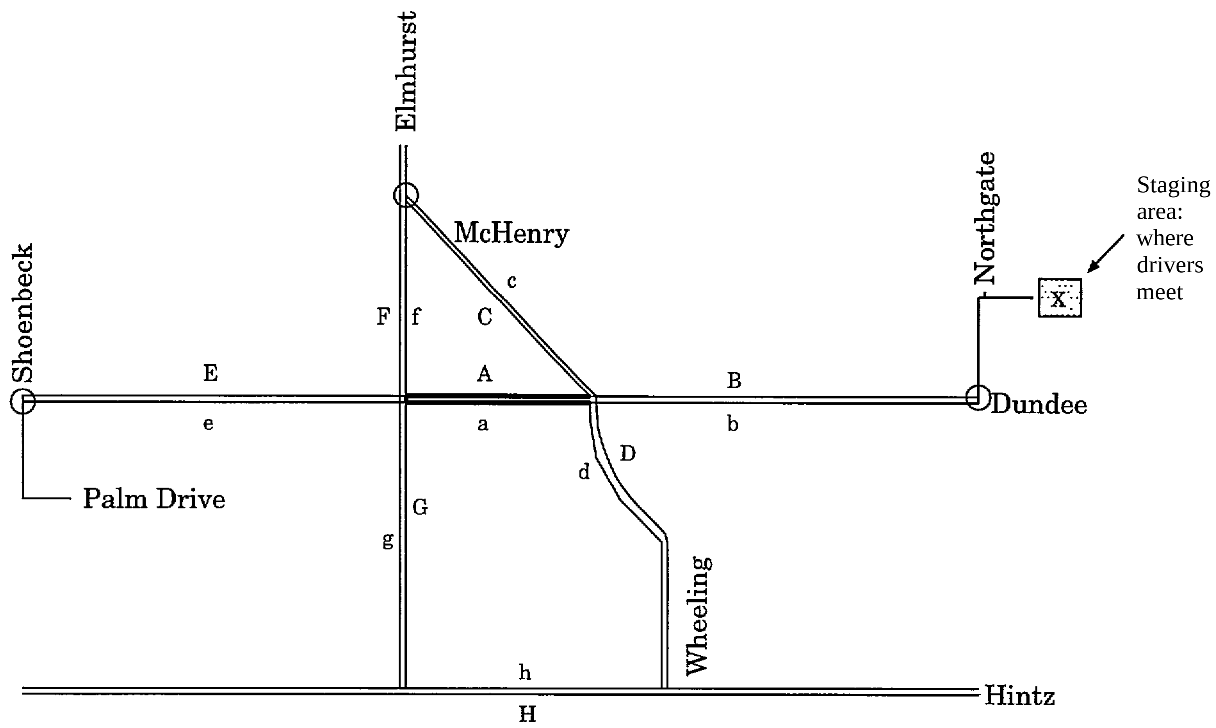

Figure 1: Probe Data Collection: Turning-Relationships Links

- In order to compute the differences in travel times between vehicles traveling straight ahead through an intersection and vehicles executing a turn, it was necessary to have at least one vehicle executing each movement. However, it would be difficult to have drivers of the probe vehicles drive 'normally' and yet travel the through-movement and turning links simultaneously. Besides it is the difference in averages that is of concern here.

- It was necessary to cover several different links and different types of intersections.

- It was necessary to avoid biases due to driver styles by having, for example, the same driver always executing a left turn or always executing a through movement.

- It was necessary to avoid biases due to previous movements executed.

Therefore, a randomized design was constructed. A set of routes was constructed and drivers were asked to follow an assigned sequence of these routes. The method of constructing the routes is detailed below [we acknowledge the help given by Jerry Sacks and Alan Karr of the National Institute of Statistical Sciences]:

1. Each route started from one of 3 fixed points (at Northgate, Palm Drive or at Hintz Road - see Figure 1).

2. At each intersection the movement to be executed was determined randomly. Probabilities were assigned for each movement. For example, the probabilities for a probe

vehicle traveling on Link A making a right turn, left turn or through movement were 0.33, 0.33 and 0.33. The probabilities were assigned in order to get appropriate coverage levels for each movement. For example, since Link A was critical for our analysis, the through movement probability for Link B was 1.0, while the left-turn probability for Link D was 0.67. Using these probabilities routes were constructed using Monte Carlo methods.

3. The route ended when it reached the starting point for the next route in the sequence.

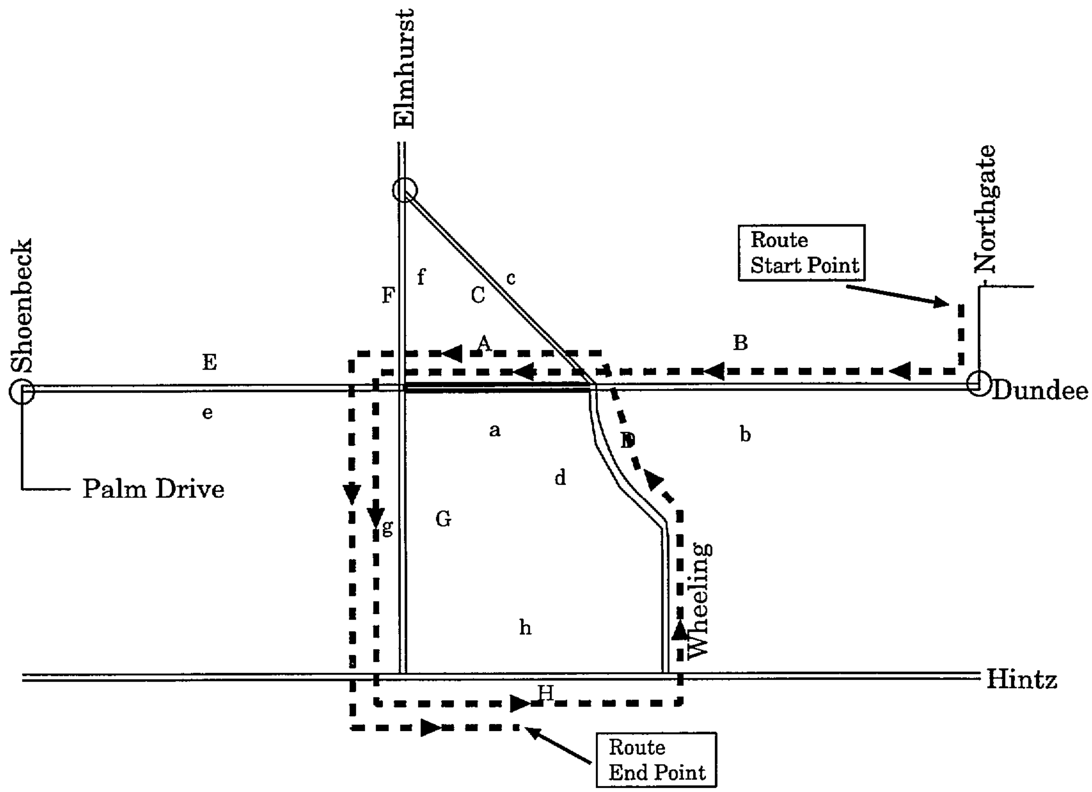

Figure 2: Example of a Turning-Relationships Data-Collection Route

Clearly these routes are of unequal length. An example of one of the turning-relationships data-collection routes is shown in Figure 2. In the Evaluation Test Plan (Urban Transportation Center, 1995) we identified the section of Dundee Road (between Elmhurst and Wheeling/McHenry) as the target section of Dundee Road for the evaluation of relationships among turning movements. Although the majority of probe traversals were on these links, we have also analyzed data from other road segments on the study routes where through-movement and turning-movement travel-time data are available.

Since the routes were frequently long and rarely did a driver drive the same route twice, special instructions had to be given to drivers. As the turning-relationships data-collection exercise came at the end of 11 weeks of data collection, our drivers had gained a great deal of experience with the vehicles and were familiar with the purpose of the data collection. Also, as we generally used a smaller number of vehicles for this exercise, we needed fewer drivers and were able to select those drivers who appeared to be most capable of following the detailed instructions for this particular data-collection exercise.

3.3 Driving Schedule

Data were collected on the turning-relationships study routes Monday through Thursday from July 24th to August l0th, and on one Friday, August 4. At the beginning of each day of data collection, a twelve-noon briefing was held at the ADVANCE office in Schaumburg. At this time the drivers were assigned vehicles and they left the office at approximately 12:30 pm. Data were collected by probe vehicles driven on the study routes between 1:00 pm and 7:00 pm with breaks as described below.

On each day of data collection a field manager was present at the staging area. The field manager ensured that vehicles were driven on the study route at satisfactory headways and instructed drivers when to take breaks.

The drivers were given a ten-minute break at approximately 2:00 pm and another one from approximately 6:00 pm to 6:l0 pm. Each driver took his or her break at a slightly different time, since each was dispatched by the field manager to the break area as they arrived at the staging area. During breaks each probe vehicle was inactive for more than ten minutes as time was lost off-route and also because the vehicle and MNA needed warm-up time. A 1onger break occurred from 3:30 pm to 4:00 pm. After this break, during the two-hour peak period from 4:00 pm to 6:00 pm, the drivers operated their vehicles without scheduled breaks.

3.4 Data Analysis

Vehicles were driven on the turning-relationships routes as described above. For the purposes of our analysis of the relationships among travel times we required travel-time data for those 5-minute intervals where travel times are available for the two movements (i.e., a turning and a through movement) which are the subject of our comparison. For example, on target link A on Dundee Road we analyzed data from every five-minute interval for which travel times are available for the left turn and through movement (396 5-minute periods) and for the right turn and through movement (374 5-minute periods).

Table 1 shows the sample sizes (i.e., the number of 5-minute intervals) from Target Link A, Link a and all other links where turning and through-movement travel times were available for comparison. The naming system used in this table (and throughout the report) is that the upstream and downstream links — as shown on Figure 1 — for the turning or through movement are given. For example, the movement identified as Af is the right turn from Dundee Road to Elmhurst Road. It can be seen from this table that in addition to the target links on Dundee Road we gathered useful data from McHenry Road, Wheeling Road and Elmhurst Road. All the links for which sample sizes are shown in Table 1 were used in our evaluation of the constants added to through-movement travel times to predict turning-movement travel times. The regression analysis was performed to predict the travel time for the left turn from Dundee Road to Elmhurst Road (Link Ag).

Table 1: Relationships among Travel Times: Sample Sizes for Data Analysis

Link		# 5-minute intervals
Dundee Road westbound:		
Ag-AE (left turn-through)	Off-Peak	191
	Peak	205
Af-AE (right turn-through)	Off-Peak	183
	Peak	191
Dundee Road eastbound:		
ac-ab (left turn-through)	Off-Peak	103
	Peak	113
ad-ab (right turn-through)	Off-Peak	79
	Peak	89
McHenry Road:		
Cb-Cd (left turn-through)	Off-Peak	7
	Peak	8
Ca-Cd (right turn-through)	Off-Peak	19
	Peak	20
Wheeling Road:		
DA-Dc (left turn-through)	Off-Peak	33
	Peak	32
Db-Dc (right turn-through)	Off-Peak	15
	Peak	15
Dundee Road (eastbound):		
ef-ea (left turn-through)	Off-Peak	8
	Peak	—
eg-ea (right turn-through)	Off-Peak	7
	Peak	
Elmhurst Road (southbound):		
Fa-Fg (left turn-through)	Off-Peak	17
	Peak	14
Elmhurst Road (northbound) :		
Ga-Gf (right turn-through)	Off-Peak	9
	Peak	12

4 Results: Comparison of Travel Times

4.1 Dundee Road Target Links

As described in the Evaluation Test Plan, the turning-relationships analysis will focus on the target links on the section of Dundee Road between Wheeling/McHenry and Elmhurst (see Figure 1). Link A is the westbound link and Link a is the eastbound link.

4.1.1 Link A: Westbound

Link A on Dundee Road is a westbound link terminating at the intersection with Elmhurst Road. Vehicles may proceed straight ahead along Dundee Road, or they may turn left or right onto Elmhurst Road. This section of Dundee Road has two lanes, however at the approach to the intersection with Elmhurst there is a dedicated left-turn lane. Left-turning traffic receives a left-turn green arrow at the beginning of or preceding the green phase for Link A. Right-turning traffic may proceed through the intersection on red; right-turning vehicles do not however have a dedicated lane. The configuration of Link A is illustrated in Figure 3.

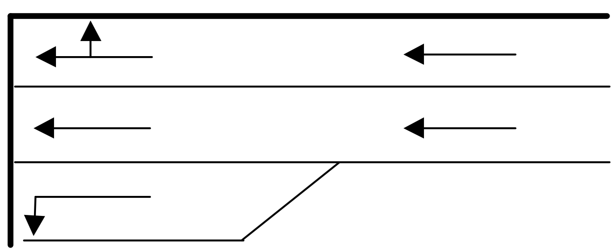

Figure 3: Link A: Intersection-Approach Configuration

Relationships among travel times on through movements and left and right turns on Link A, westbound on Dundee Road, are shown as histograms in Figure 4. Each histogram presents the frequency of each observed difference (in seconds) between the turning-movement travel time and the through-movement travel time. Superimposed on each histogram is an arrow indicating the value of the difference between the BD estimate (from the NFM) for the turning-movement travel time and the BD estimate for the through-movement travel time. Table 2 presents summary statistics for each turning/through-movement travel-time difference. Note that the mean of each difference is not particularly relevant to the comparison of the BD estimates with observed travel-time differences. Each travel-time difference is computed by subtracting the mean of all through-movement travel times from the mean of all turning-movement travel times in a given five-minute interval. We are more concerned therefore with how often (i.e. during how many five-minute intervals) the travel time difference obtained from the NFM (i.e., the BD estimate) is replicated by the travel time difference reported by probe vehicles. This is the information presented in the frequency histograms.

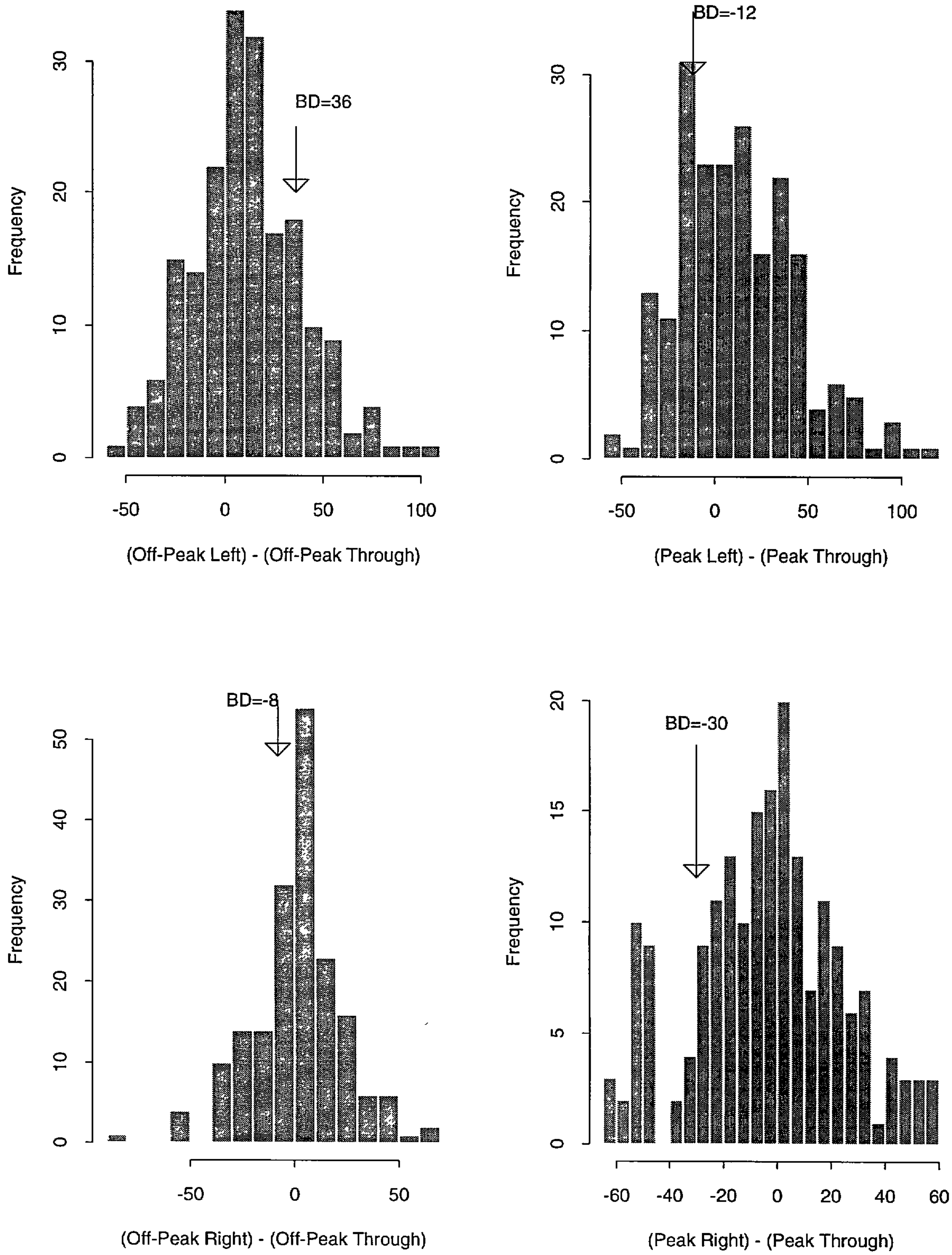

Figure 4: Relationships among Travel Times: Target Link A
Note: The x-axis of each histogram shows the difference (in seconds) between the turning-movement travel time and the through-movement travel time. The y-axis of each histogram shows the frequency (number of five-minute intervals) for which each difference in through-movement and turning-movement travel times was observed.

Table 2: Summary Data for Difference between Turning and Through-Movement Travel Time: Link A

Travel Time Difference		Mean	Median	variance	s.d.	BD Estimate
(left) - (through)	Off-Peak	11.6	10.0	774.0	27.8	36
	Peak	12.3	10.0	1008.6	31.8	-12
(right) - (through)	Off-Peak	2.0	3.2	495.2	22.3	-8
	Peak	-3.6	-2.5	759.3	27.6	-30

The value of the BD estimate for the difference between the turning-movement travel time and the through-movement travel time is close to the mode of the frequency of this difference in two of the four histograms on Figure 4, those relating to the peak-period left turn and the off-peak right turn. For the peak-period left turn, 88 of the 205 observed travel-time differences are within +/- 20 seconds of the BD estimate, -12. For the off-peak right turn 118 (65%) of the 183 observed travel-time differences are within +/- 20 seconds of the BD estimate of -8, and 55 are within +/- 10 seconds of the BD estimate.

The BD estimates are further from the modal value of the observed travel-time differences for the off-peak left turn and the peak period right turn. In both these cases the BD estimate differs by more than 20 seconds from the mode of the frequency of the observed difference. Based on the findings presented in Figure 4 few conclusions can be reached on whether the BD estimate more closely approximates the the difference between the through movement and left-turn or right-turn travel time, or is more accurate in the peak or off-peak periods.

4.1.2 Link a: Eastbound

Link a occupies the same segment of Dundee Road as Link A described above. Link a however is the eastbound link with traffic in the opposite direction to that on Link A. Link a terminates at the intersection of Dundee Road with Wheeling and McHenry Roads. Vehicles on Link a may proceed straight ahead along Dundee Road, they may turn left onto McHenry Road or they may turn right onto Wheeling Road. The configuration of Link a at this intersection is similar to that described for Link A above. Link a has two through-traffic lanes and a dedicated left-turning lane, left-turning traffic receives a green arrow at the start of or preceding the green phase.

The relationships among travel times on through movements and left and right turns on Link a, eastbound on Dundee Road, are shown as histograms in Figure 5. Again, summary statistics for each turning/through-movement travel-time difference are shown (Table 3).

The position of the arrows (for BD estimates) on the histograms in Figure 5 suggests that the BD estimates for turning movements are generally more accurate on this link than for the link described above (Link A, for which the sample size of 5-minute intervals was larger). Again the BD estimate for the left-turning movement in the peak period appears to be relatively accurate; 40 of the 113 probe-reported travel-time pairs in the peak period give a value for left-turn travel time minus through-movement travel time of +/- 20 seconds of the BD estimate. The BD estimate for the off-peak left turn is also relatively accurate; 59 of the 103 probe-reported travel-time differences are within +/- 20 seconds of the BD estimate.

The BD estimates for right-turning traffic (the estimate of zero indicates the right-turning travel time is not predicted to differ from that for the through movement) appear to be accurate with reference to the probe-reported travel time differences for right turns and through movements. In the off-peak 43 of the 79 travel-time differences are within +/- 20 seconds of the BD estimate, in the peak period 42 of the 89 travel-time differences are within +/- 20 seconds of the BD estimate. For Link a, the BD estimates are more accurate for the right-turning movement. However, the left turn is clearly the more interesting case.

Table 3: Summary Data for Difference between Turning and Through-Movement Travel Time: Link a

Travel Time Difference		Mean	Median	variance	s.d.	BD Estimate
(left) - (through)	Off-Peak	22.7	17.5	1108.7	33.3	24
	Peak	41.7	42.5	1551.3	39.4	30
(right) - (through)	Off-Peak	-0.6	0.0	758.7	27.5	0
	Peak	4.6	7.0	1519.8	39.0	0

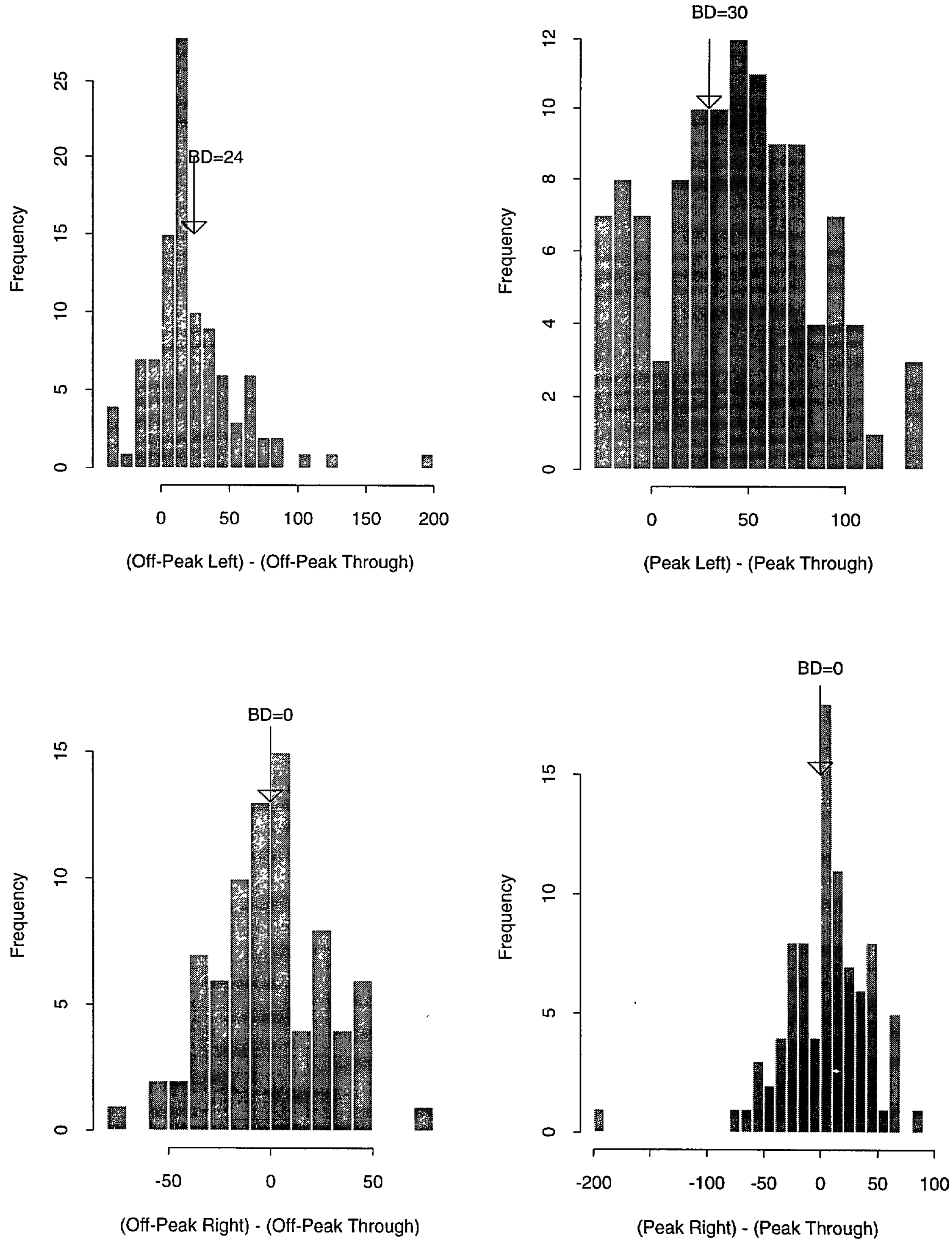

Figure 5: Relationships among Travel Times: Target Link a
Note: The x-axis of each histogram shows the difference (in seconds) between the turning-movement travel time and the through-movement travel time. The y-axis of each histogram shows the frequency (number of five-minute intervals) for which each difference in through-movement and turning-movement travel times was observed.

4.2 Other Links on the Study Routes

Although the target links described above are the main focus of this analysis we have also analyzed turning relationships on other links on the study routes. In this case we have only analyzed those cases where, for 5-minute interval data, we have probe data for both turning and through movements to allow comparison of travel times.

4.2.1 Other Links, Off-Peak Period

In the off-peak period, eight road segments on the study routes were available for analysis in addition to the Dundee Road target links. The relationships among travel times on through movements and left and right turns on the non-target links for which data are available for the off-peak period are shown on the histograms in Figure 6. Some of the pairs of travel times analyzed had very few observations (Table **1)** and therefore reveal little of use. However, where a reasonable number of 5-minute intervals were available for analysis, for example the left-turn/through-movement pair of links on Wheeling Road northbound [(Left TurnDA)-(Through MovementDc)] for which thirty-three 5-minute periods were analyzed, the results of the analysis are similar to those presented for the Target Links, A and a. That is, there is general agreement but not absolute agreement between the BD estimate for the left-turn movement and the left-turn travel times experienced by the probes.

4.2.2 Other Links, Peak period

Fewer road segments (only six) were available for analysis in the peak period. The relationships among travel times on through movements and left and right turns on the non-target links for which data are available for the peak period are shown on the histograms in Figure 7. Again, there is a reasonable sample (thirty-two 5-minute periods) on the Wheeling Road northbound left-turn and through-movement pair (Left Turn_DA)-(Through MovementDc). The histogram for this pair of movements again shows close agreement between the BD estimates and probe-reported left-turn travel times. The right-turn and through-movements on McHenry Road southbound, (Right Turn-CA)-(Through Movement-Cd), also had a reasonable sample size (twenty 5-minute intervals) and also show good (but not exceptional) agreement between the BD estimate and probe travel times for the right turn.

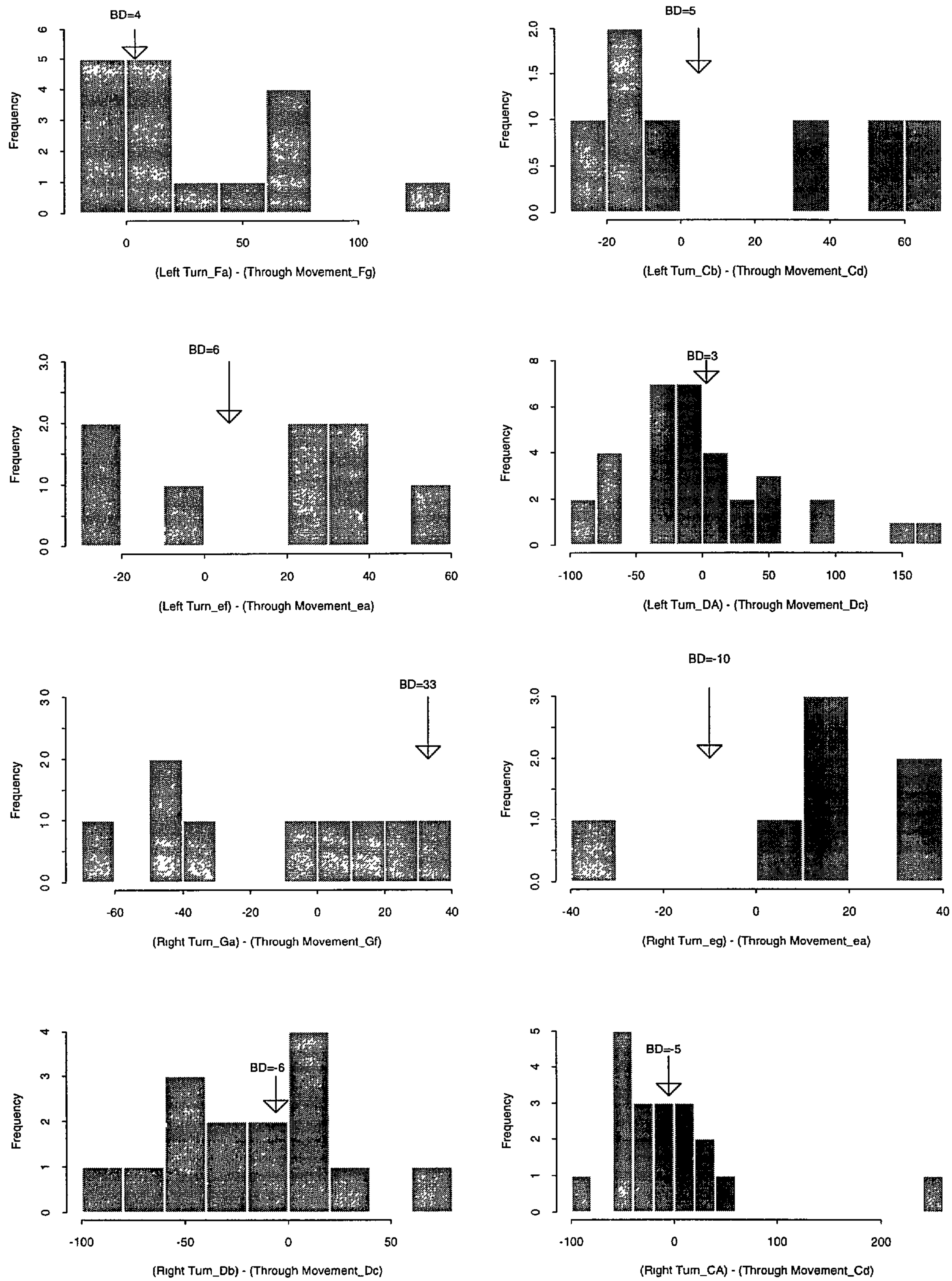

Figure 6: Relationships among Travel Times on Non-Target Links: Off-Peak Period
Note: The x-axis of each histogram shows the difference (in seconds) between the turning-movement travel time and the through-movement travel time. The y-axis of each histogram shows the frequency (number of five-minute intervals) for which each difference in through-movement and turning-movement travel times was observed.

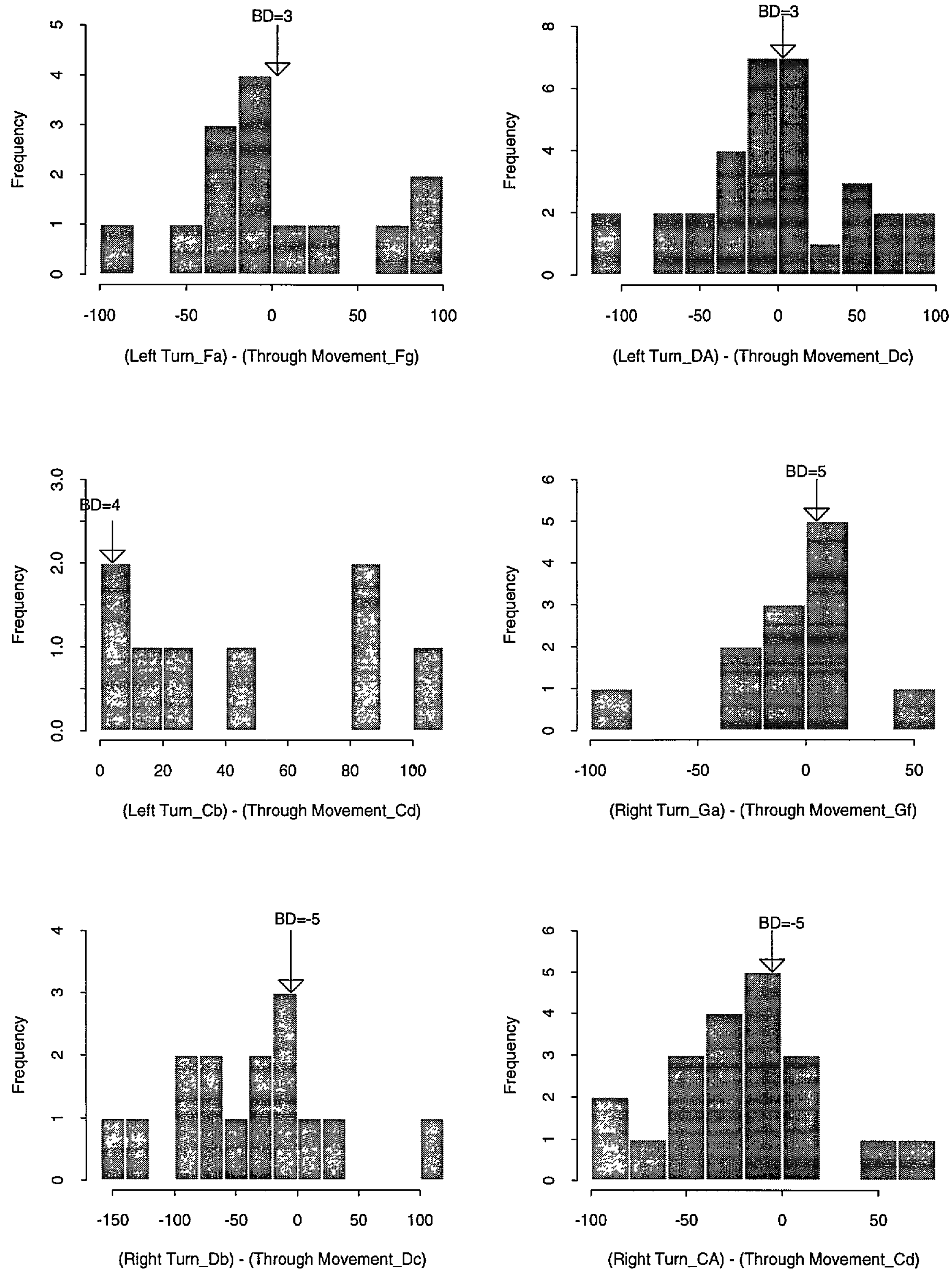

Figure 7: Relationships among Travel Times on Non-Target Links: Peak Period
Note: The x-axis of each histogram shows the difference (in seconds) between the turning-movement travel time and the through-movement travel time. The y-axis of each histogram shows the frequency (number of five-minute intervals) for which each difference in through-movement and turning-movement travel times was observed.

Table 4: Summary Data for Difference between Turning and Through-Movement Travel Time: Other Links on the Study Route

Travel Time Difference		$n =$	Mean	Median	variance	s.d.	BD Estimate
(left_Fa) - (through_Fg)	Off-Peak	17	26.7	10.0	1784.6	42.2	4
	Peak	14	3.1	-11.5	2773.4	52.7	3
(left_Cb) - (through_Cd)	Off-Peak	7	15.0	-5.0	1303.3	36.1	5
	Peak	8	46.0	33.5	1744.9	41.8	4
(left_ef) - (through_ea)	Off-Peak	8	15.9	25.2	979.9	31.3	6
	Peak	—	—	—	—	—	—
(left_da) - (through_dc)	Off-Peak	33	2.3	-9.0	3952.6	62.9	3
	Peak	32	-1.9	-2.3	2608.6	51.1	3
(right_Ga) - (through_Gf)	Off-Peak	9	-12.7	-1.0	1276.3	35.7	33
	Peak	12	-7.2	-1.3	1144.3	33.8	5
(right_eg) - (through_ea)	Off-Peak	7	13.9	18.0	621.0	24.9	-10
	Peak	—	—	—	—	—	—
(right_Db) - (through_Dc)	Off-Peak	15	-14.8	-17.0	1806.5	42.5	-6
	Peak	15	-37.6	-29.0	4154.2	64.5	-5
(right_CA) - (through_Cd)	Off-Peak	19	-2.4	-17.0	5007.5	70.8	-5
	Peak	20	-22.2	-20.2	1640.2	40.5	-5

4.3 Regression Models to Predict Left-Turn Travel Time on Target Link A

The regression analysis was performed on the segment of the study route with the largest number of probe reports, Target Link A (see Table **1).** The intersection of Dundee Road with Elmhurst Road has volume detectors on all approaches; five-minute aggregate detector volumes were used in the regression analysis.

In order to predict left-turn travel time we constructed three regression models with different inputs as the independent variables. In the first model we used only through-movement travel times as predictors. In the second model, in addition to through-movement travel times, we included traffic-volume data from the detectors on the four intersection approaches. Finally we used signal information in the regression model. The results from each regression analysis (performed using SAS) are presented below.

4.3.1 Regression Model 1: Using Through-Movement Travel Time

The analysis of variance table and parameter estimates from the regression performed to predict left-turn travel times on Link A from through-movement travel times on Link A are shown in Table 5. In this model the five-minute mean travel time for the through movement is used to predict each individual left-turn travel time.

Table 5: Analysis of Variance and Parameter Estimates: Regression Model 1

F-value	3.58
Prob > F	0.059
Root MSE	27.61
R-square	0.0058

Parameter Estimates:

Independent Variable	Parameter Estimate	Standard Error	T for H_0: Parameter = 0	Probe > |T|
Intercept	59.56	3.26	18.25	0.0001
$TT_{through}$	0.11	0.06	1.89	0.059

The critical value of F at the 1% level of significance with 1 and 609 degrees of freedom is 6.7, The F-value from this analysis is less than the critical F-value (3.58 < 6.7) therefore we cannot reject the hypothesis that the slope of the regression is zero at a 1% level of significance. Even at a 5% level of significance (critical value of F = 3.85) we cannot reject the hypothesis that the slope of the regression is zero, although the situation is more borderline now. However, because the residuals are very large and the regression line is not a good fit for the data ($R^2 = 0.0058$), even the level of significance attained is largely due to a large sample size and it would be inadvisable to use the model for predictive purposes.

Figure 8 shows a plot of each left-turn travel time vs. the corresponding five-minute mean through-movement travel time (that is, the data used in the regression model). The figure also shows the best-fit regression line $\hat{y} = a + bx$, ($\hat{y} = 59.56 + 0.11x$). This plot confirms the poor fit of the regression.

As the R^2 illustrates, the predictive ability of this model is very slight. Indeed, the most significant term is the intercept which actually turns out to be the best prediction of left-turn travel time. This leads to the conclusion that a constant (e.g., obtained from the NFM or subsequent static-profile updates) added to the through-movement travel time would do about as well as this simple regression model in predicting left-turn travel times from known through-movement travel times.

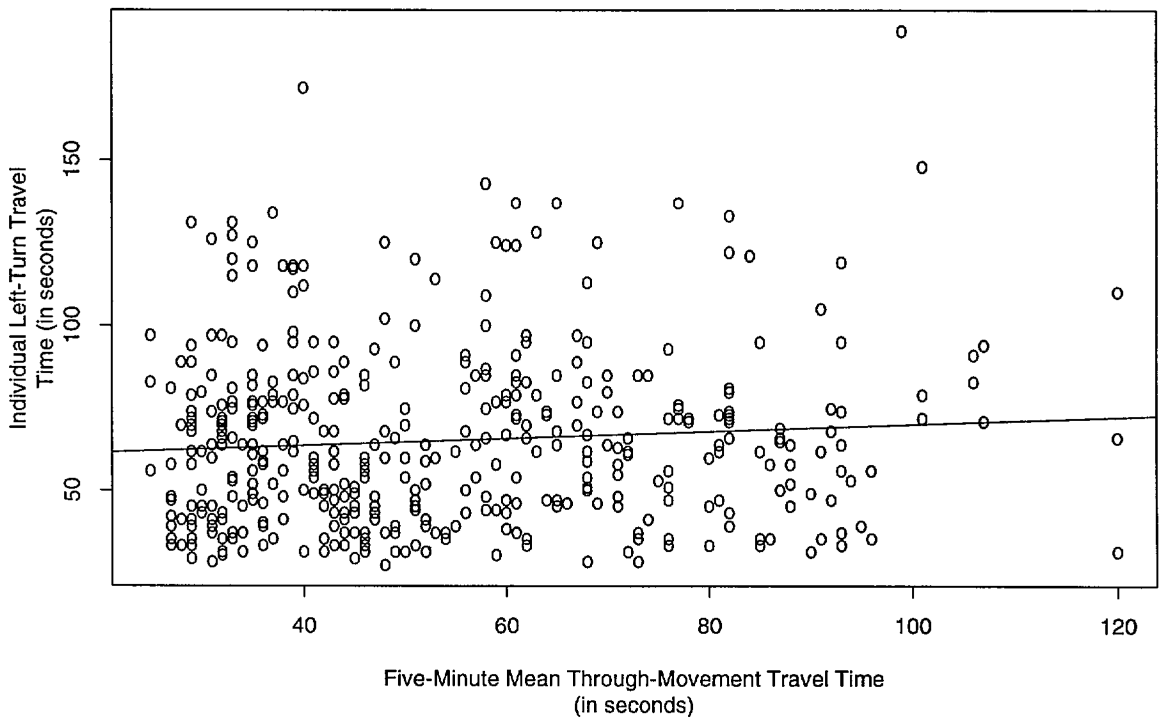

Figure 8: Left-Turn Travel Time by Through-Movement Travel Time: Target Link A

4.3.2 Regression Model 2: Using Detector Traffic Volumes

In order to improve on the results obtained from the first regression model, the second regression model includes data on through-traffic, cross-traffic and opposing-traffic volumes to predict left-turn travel times. The variables used to predict left-turn travel time on Link A in the second regression model are 5-minute mean through-movement travel time on Link A and five-minute aggregated detector volumes on the four approaches to the intersection — Dundee Road eastbound, Dundee Road westbound (i.e. Link A), Elmhurst Road southbound and Elmhurst Road northbound.

Table 6: Analysis of Variance and Parameter Estimates: Regression Model 2

F-value 5.26
Prob > F 0.0001

Root MSE 25.83
R-square 0.054

Parameter Estimates:

Independent Variable	Parameter Estimate	Standard Error	T for H_o: Parameter = 0	Prob > |T|
Intercept	27.14	9.86	2.75	0.0062
$TT_{through}$	0.015	0.061	0.25	0.80
$VOL_{eastbound}$	0.13	0.155	0.84	0.40
$VOL_{westbound}$	0.17	0.082	2.03	0.04
$VOL_{northbound}$	0.02	0.095	0.21	0.84
$VOL_{southbound}$	0.27	0.143	1.86	0.06

This regression model offers little improvement over the previous model. The critical value of F at the 1% level of significance with 5 and 464 degrees of freedom is 3.03. The F-value from this analysis is greater than the critical F-value (5.26 > 3.03) therefore we must reject the hypothesis that the independent variables collectively have no effect on the dependent variable. However the residuals are still very large and the regression is not a good fit for the data. The value of R^2 (R^2 = 0.054) is somewhat higher than in the previous model but, as in the previous model, indicates a poor fit.

In this way, it is not desirable to predict the left-turn travel time on Link A from through-movement travel times and detector traffic volumes on the four intersection approaches. The inclusion of traffic volumes does not noticeably improve the predictive ability of the model.

4.3.3 Regression Model 3: Using Signal Information

During the turning-relationships data-collection exercise signal phasing and timing data were gathered. Observers noted the timing of all signal changes on Link A, for example, the change from red to green with green arrow. Using the time stamp on each probe report we were able to determine the time at which each probe vehicle passed through the intersection of Dundee Road and Elmhurst. By matching these times with the manually-collected signal-timing data we noted the signal received by each vehicle passing through the intersection: red with green arrow, green *with* green arrow, or green *without* green arrow. Again we are indebted to NISS, who conducted this data-collection exercise.

In an attempt to find a good predictive model for left-turn travel time on Link A we constructed a regression model using through-movement travel times on Link A and the signal information described above. The signal information input to the model is in the form of dummy variables indicating the signal received by left-turning and through traffic (see Table 7).

Table 7: Regression Model 3: Signal Information

Dummy Variable Name	Signal Aspect	S_{left}	$S_{through}$	Travel Time Comparison
S_{left}	red with green arrow	1	0	$TT_l < TT_t$
$S_{left}S_{through}$	green *with* green arrow	1	1	$TT_l = TT_t$
$S_{through}$	green *without* green arrow	0	1	$TT_l > TT_t$

S_{left} is the signal received by left-turning traffic
$S_{through}$ is the signal received by through traffic
TT_l is the left-turn travel time
TT_t is the through-movement travel time

The analysis of variance table and parameter estimates from the regression model constructed to predict left-turn travel times on Link A from through-movement travel times on Link A and the signal information described above are shown in Table 8. The value of R^2 (R^2 = 0.54) indicates a better fit of the regression.

While the through-movement travel times and five-minute aggregated detector traffic volumes do not enhance the predictive ability of using a constant to predict left-turn travel times, the use of signal timings yields a promising model.

4.3.4 Comments on the Regression Models

The results of the regression analyses performed for Link A indicate that using known through-movement travel times and intersection-approach traffic volumes is not useful in predicting left-turn travel times. A good prediction can be made when signal timing is known. However, as described above, this information was not available to us through the ADVANCE design; it had to be gathered manually. The manually-collected signal-timing data allowed us to construct a fairly simple regression model with promising results in the prediction of left-turn travel times. These results are not entirely surprising given that the signals are demand actuated. We therefore recommend that any future attempt to

Table 8: Analysis of Variance and Parameter Estimates: Regression Model 3

F-value	210.0
Prob > F	0.0001
Root MSE	17.77
R-square	0.54

Parameter Estimates

Independent Variable	Parameter Estimate	Standard Error	T for H_0: Parameter = 0	Prob > |T|
Intercept	29.56	2.63	11.2	0.0001
$TT_{through}$	0.58	0.04	13.3	0.0001
S_{left}	-23.65	1.40	-16.9	0.0001
$S_{left}S_{through}$	-5.66	1.05	-5.42	0.0001
$S_{through}$	29.31	1.19	24.6	0.0001

predict turning-movement travel times from known through-movement travel times for a dynamic route-guidance system should use signal-timing data.

5 Conclusion

The analysis presented shows that the BD estimates for turning-movement travel times based on adding a constant to through-movement travel times are relatively accurate when compared to the turning-movement travel times experienced by probe vehicles. A future analysis of the relationships among turning movements should compare probe-reported travel times to static-profile updates [see Sen et al. (1996)] instead of BD estimates.

Our analysis of regression models constructed using left-turn travel times as the dependent variable and through-movement travel times and intersection-approach detector volumes as independent variables suggests that little is gained from the presence of these variables as compared to using a constant alone. However when signal-timing data is used as input to a regression model to predict left-turn travel times a more accurate prediction can be made. We therefore conclude and recommend that signal-timing information should be made available in future attempts to predict turning-movement travel times.

References

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Glossary

Base Data (BD)/Base Data Estimates - travel-time predictions for specific links at specific times as derived from the NFM.

Network Flow Model (NFM) - the model developed by the TRF group based upon the contents of the *ADVANCE* Network Representation (ANR). The network flow model analyzes the ANR to produce link travel times and link flows by time period and day type.

Off-Peak - that portion of the day considered to have lighter traffic flow, defined in the study as 1:00 pm-4:00 pm.

Peak - that portion of the day considered to have heavier traffic flow, defined in the study as 4:00 pm-6:00 pm.

Static Profile (SP) - static information of the roadway link including day type, link ID and average travel times for a specific time period.

Static Profile Updating (SPU) - the revision of previous Static Profile travel times for links, during specific time periods, using information gathered from probe reports and processed through the SP algorithm.

Traffic Information Center (TIC) - Consisting of the hardware, software, a centralized facility and operations personnel. It communicates to and from probe vehicles and external systems.

Traffic Related Functions (TRF) - Subsystem consisting of data fusion, vehicle dynamics, incident detection and travel-time prediction algorithms.

Travel Time Prediction (TTP) - An algorithm used in the prediction at the TIC of future short term travel times on links to develop future adjustments to the static profiles.